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Notes

ON THE SHELLY MORAINE OF THE SEFSTRÖM GLACIER
AND OTHER SPITSBERGEN PHENOMENA ILLUSTRATIVE
OF BRITISH GLACIAL CONDITIONS.¹

BY C. W. LAMPLUGH, F.R.S., F.G.S.

WITH A NOTE BY A. STRAHAN, SC.D., F.R.S.; AND LIST OF SHELLS
BY PROF. GERARD DE GEER.

(Read March 9th, 1911.)

INTRODUCTION.

Last summer (1910) I was fortunately able to join the cosmopolitan party of geologists who visited Spitsbergen under the guidance of Prof. G. De Geer before the eleventh meeting of the International Geological Congress in Stockholm. From beginning to end, the journey was crowded with interest; and, as a British glacialist, I was, above all, impressed with the instructiveness of the glacial phenomena, both ancient and recent.² The glaciation of the Scandinavian peninsula itself, of which we saw the general outlines in our land-journeys between Stockholm and two separate points on the Norwegian coast, carries much that is enlightening in respect to our British drifts;³ but in the present communication I shall confine myself to the experiences gained in Spitsbergen. Of the places visited there, the moraine of the Sefström Glacier was of pre-eminent interest in the elucidation of our shelly drifts, and will be more particularly described. Certain phenomena associated with the Nordenskiöld and Von Post glaciers, that are instructive in relation to our drifts, will also be noticed; and the local descriptions will be prefaced by some general observations on the Glacial conditions in Spitsbergen which are likely to be of interest to the British glacialist.⁴ The route followed by the party in Spitsbergen is shown in Fig. 1.

¹ An abstract of this paper was delivered at the Sheffield Meeting of the British Association, 1910 (Section C.).

² I have given a general account of the journey, in an article "Stockholm to Spitsbergen: The Geologists' Pilgrimage," in *Nature*, Vol. LXXXV., No. 2144 (Dec. 1st, 1910), pp. 152-7.

³ Since this paper was written, an excellent discussion of the same subject, entitled "Glacial Features in Spitsbergen in relation to Irish Geology" has been published by a member of our party, Prof. G. A. J. Cole, in *Proc. Roy. Irish Academy*, Vol. XXIX., Section B., No. 5 (July, 1911), pp. 191-208, with 16 photographic illustrations. The reproductions of Prof. Cole's own photographs which adorn this paper afford illustrations of most of the features that I have described in the context, and his descriptions cover some points which I have not dealt with.

⁴ For a fuller discussion of Spitsbergen glaciers and their general bearing on the problems of Glacial geology, see two excellent papers, "Contributions to the Glacial Geology of Spitsbergen," by Prof. E. J. Garwood and Prof. J. W. Gregory, *Quart. Journ. Geol. Soc.*, Vol. LIV. (1898), pp. 197-225, and "Additional Notes on the Glacial Phenomena of Spitsbergen," by Prof. E. J. Garwood, *Ibid.*, Vol. LV. (1899), pp. 681-9.



Photographed by Oscar Halldin, Stockholm.

Mount Temple, on the northern shore of Sassen Bay, Ice Fjord. Showing an escarpment of Carboniferous rocks, with huge talus-slopes; and with Raised Beaches in the foreground.

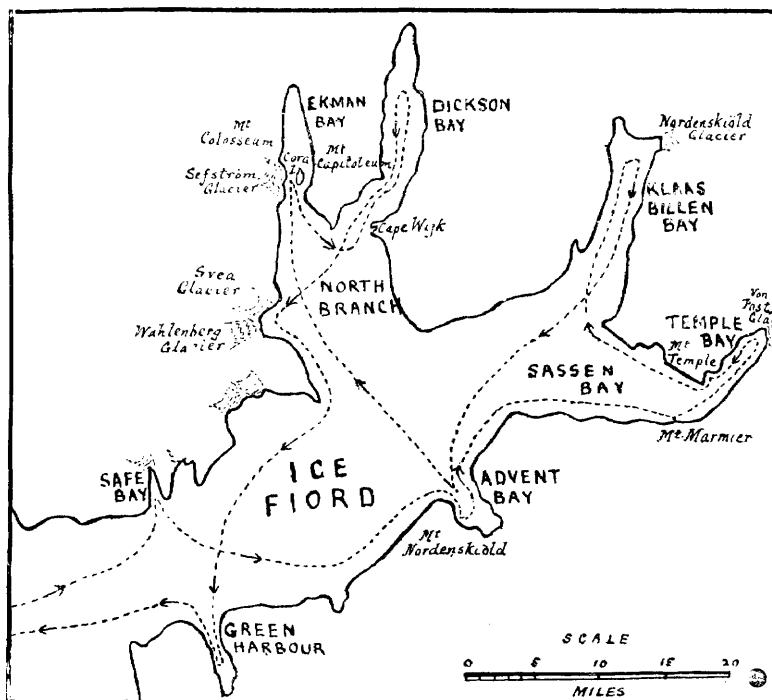
Reproduced by permission of Prof. G. De Geer.

Proc. Yorks. Geol. Soc., Vol. XVII., Plate XXV.

FIG. 1.

Sketch-map of Ice Fiord, Spitsbergen.

The dotted line shows the route of the Geol. Congress Party.



Reproduced, by permission, from "Nature," Dec. 1st, 1910.

In the short time spent at the various spots, thorough investigation was out of question, but even brief observation was sufficient to bring out many points of consequence. We had, besides, the great advantage of Prof. De Geer's previous knowledge of the ground, which he placed unreservedly at our service, although many of his results have not yet been published; and through his guidance we were enabled to make full use of every opportunity. In recording my own observations, it will, of course, be understood that they are merely repetitions of those made previously by Prof. De Geer; and it is with his generous consent that I bring them together in this paper. A brief account of most

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of the Spitsbergen glaciers that we visited, with large-scale maps of several that have been carefully measured, is contained in Prof. De Geer's "Guide de l'Excursion au Spitzberg" (Stockholm, 1910), which was placed in our hands when we started on the journey. To this publication I am indebted for all the data respecting the movements and dimensions of the glaciers.

FORMER GLACIATION OF SPITSBERGEN AND PRESENT CONDITIONS.

From the researches of the Scandinavian geologists we know that during some portion of Quarternary time, presumably during the Glacial Period of lower latitudes, nearly the whole of Spitsbergen was buried under ice, and all the great fiords, such as Ice Fiord, were filled with confluent glaciers.¹ It is remarkable, however, how scanty are the remaining traces of this great glaciation on the present tracts of bare land. The only indubitable relics of these former conditions that came under my notice in the parts that we visited were a few transported blocks, in some cases reduced to patches of frost-riven splinters, on the bare plateaus and escarpment-slopes; as, for example, on the upland above Cape Wijk.

In the long interval since this period of glaciation, there has been a time when the land stood lower than it does now, as is shown by the successive terraces of raised beach, which are strikingly displayed in most of the branches of Ice Fiord (see Pl. XXV.), where the highest beach recognized by De Geer lies about 430 feet (130 m.) above present sea-level. During this stage, the climate appears to have been less severe than now, as some of the existing glaciers which come down to the sea in the northern arms of Ice Fiord have encroached upon the raised beaches, showing that there was less ice in the valleys when these beaches were formed. Moreover, the shells contained in the lower beaches bear witness to a somewhat milder climate than that of to-day, as they include at least three species—*Litorina rudis*, *Cyprina islandica* and *Mytilus edulis*—which are not now living in Ice Fiord; and

¹ For a good general account and résumé of the geology of Spitsbergen, including the Glacial and Post-glacial phenomena, see "Beiträge zur Geologie der Bären-Insel, Spitzbergens und des König-Karl-Landes," by Prof. A. G. Nathorst, *Bull. Geol. Instit. of Upsala*, Vol. X. (1910), pp. 261-415, in which full references are given to the previous literature.

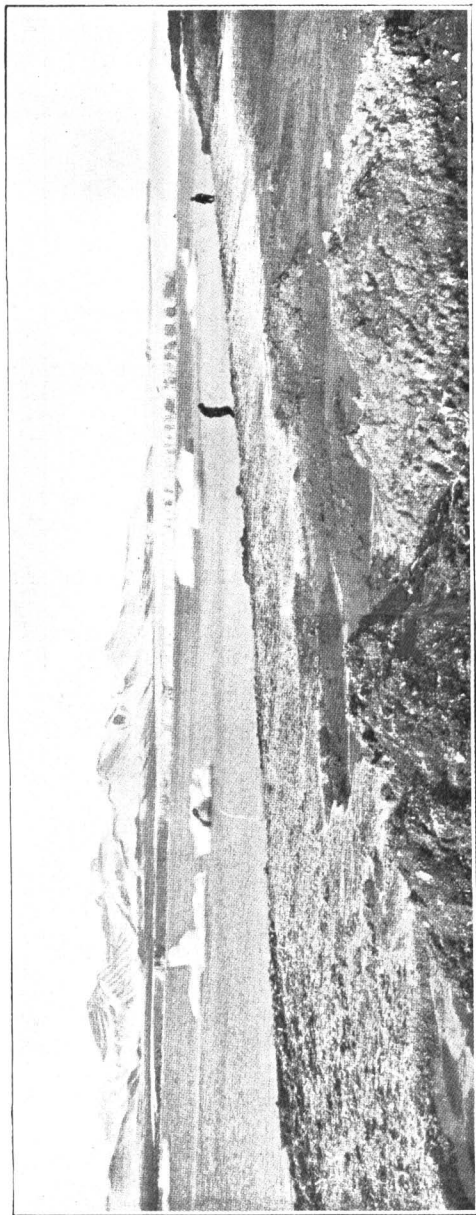


Fig. a.

Söström Glacier in recession 1908, having left since 1896 the moraine in the foreground with masses of marine shells pushed up from the sea-bottom.

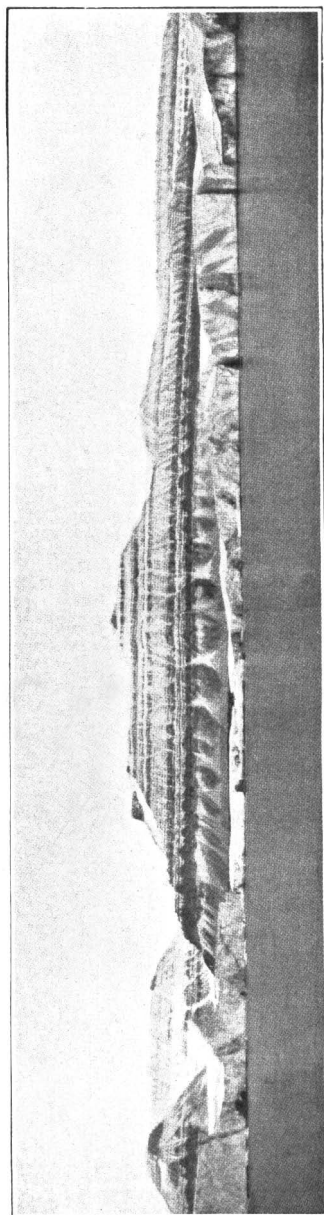


Fig. b.

Mt. Capitolcum, Carboniferous from Ekman Bay, with glacier-island in the foreground.

Proc. Yorks. Geol. Soc., Vol. XVII., Plate XXVI.

(Reproduced by permission of Prof. G. De Geer, from "Guide de l'Excursion au Spitzberg.")

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similar indications of less severe cold have been detected in a few plant-remains from superficial peaty deposits.¹

For the British glacialist, it is of peculiar service to find in Spitsbergen the effect of glacial conditions on stratified rocks analogous in structure and texture to those of Southern Britain. In nearly all the other accessible regions of present glaciation the prevalent rocks are of the hard or massive type ; but over a large part of Spitsbergen, including practically the whole region bordering on Ice Fiord, the formations, ranging from Palæozoic to Tertiary, contain thick masses of shale, marl, fissile sandstones, limestones, etc., essentially similar in lithological character to the equivalent formations of Britain, from which our boulder-clays have been mainly derived. Under arctic conditions these rocks crumble down readily, so that enormous masses of talus are formed under all the escarpments (see Pl. XXV.) and even on the level plateaus, while the frosted shales slide down in mud-flows at every thaw. I was everywhere strongly impressed with the huge quantity of loose material that lay ready for conversion into glacial drift if it should be caught by a recrudescence of the land-ice ; and often the material would require very little kneading to be made forthwith into a good boulder-clay.

SPITSBERGEN GLACIERS.

In West Spitsbergen at the present time the system of glaciation is, on the whole, of the Valley or Alpine type, strongly modified, however, by the severity of the climate and consequent low altitude of the snow-fields. While many of the smaller glaciers have their origin in independent snow-basins, most of the bigger ones are fed from wide snow-fields which cover a large portion of the interior plateaus ranging between 1,500 and 3,000 feet in elevation. These extensive snowfields in many instances contain ice-sheds from which separate glaciers radiate in different directions ; but they are nearly always dominated by peaky mountain-ridges on which in the summer there is much bare rock. In North-east Land, a separate island of the Spitsbergen archipelago, the conditions are known to approximate more closely to

¹ See G. Andersson, "Die jetzige und fossile Quartärflora Spitzbergens als Zeugnis von Klima-änderungen" ; and A. S. Jensen and P. Harder, "Post-glacial changes of climate in Arctic regions as revealed by investigations on marine deposits" ; both in *Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit* (Stockholm, 1910).

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the true Ice-sheet or Greenland type of glaciation, the major part of the land being covered by a thick mantle which obliterates all its irregularities ; but in West Spitsbergen, even where the ice-mantle is broadest, its shape and slope are mainly dependent upon the outlines of the land.

If the winter precipitation were heavier, there is no doubt that the present climate is cold enough to foster a vast extension of the West Spitsbergen ice-fields. As the island has been, until the last two or three years, uninhabited during the long winter save by an occasional hunter or exploring party, we have few data on which to estimate the total annual precipitation. At Treurenberg Bay in the north-eastern part of West Spitsbergen, the records of a Swedish scientific expedition¹ give the precipitation for the year, August, 1899 to August, 1900, by one method of observation as 176.49 mm. (about 7 inches), and by another method as 158.03 mm. (about 6¼ inches), more than two-thirds of which fell during the summer and autumn. But it is known that the rate varies greatly in different parts of the island, and it is thought that the average may reach about 10 inches per annum. This implies that the climate is essentially arid, like that of many other high arctic and antarctic lands ; though in high latitudes aridity is disguised by the fact that the moisture falls almost entirely in the form of snow, and remains more or less permanently at the surface. In the tropics, with the same precipitation the land would be a waterless desert during most of the year.

The precipitation is greatest near the west coast, along the mountainous ridge which culminates in the north in peaks of over 4,000 feet ; and it is in this region that the glaciers are most numerous and that they most frequently descend to the sea. In the interior, many of the valleys are empty of ice or contain glaciers only at their heads or in their minor branches ; and with our present imperfect knowledge of the country, it is often difficult to understand the local conditions which have determined the presence or absence of ice-streams in contiguous and apparently similar valleys. In the country around Ice Fiord—the part of the island that we visited—the tide-water glaciers are practically confined to the northern shores and inlets of the Fiord, while on

¹ “ *Missions Scientifiques pour la Mesure d'un Arc du Meridian au Spitzberg.*” *Mission Suédoise*, tome II., Sec. VIII. *Météorologie* (1904), pp. 214-5.



Photographed by Prof. R. S. Tarr.

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Looking north through the strait between Cora Island (on right) and Sefström Glacier (on left), showing detached snout of glacier adhering to island.

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its southern side the valleys are nearly or quite empty. Ice Fiord runs eastward into the land for about 60 miles, with a breadth varying between 5 and 15 miles, and with several deep arms or 'bays' branching northward and southward from it, of which the northern are the longer (see Fig. 1). The tide-water glaciers of its northern bays include several that have particular interest for the glacialist, and of first importance among them is the Sefström Glacier of Ekman Bay.

SEFSTRÖM GLACIER.

Simply as a spectacle, the Sefström Glacier is most impressive, both in itself and in its splendid setting (Pl. XXVI.). Bold and shapely mountains, composed mainly of Carboniferous rocks, rise above it on either side—Mt. Colosseum (1,970 ft.) on the north; Mt. Bertil (2,040 feet) on the south—while the wonderful front of Mt. Capitoleum (2,790 ft.) with its exquisite sculpturing towers up majestically on the opposite side of the narrow bay. The ice-cliffs of the glacier are constantly breaking away with uproar and commotion into the sea, so that the bay is dotted with pale blue floes of fantastic shape that drift slowly outward with the tide. Its front upon the sea is about $4\frac{1}{2}$ miles wide, and its sea-cliffs at their highest reach nearly 300 feet.

As the result of recent studies, we know that several of the Spitsbergen glaciers—perhaps all—are subject to spasmodic fits of rapid and tumultuous advance, alternating with longer intervals of retreat and ablation during which they become relatively stagnant. Prof. De Geer has traced the history of such movements in several cases.¹ In describing them to us personally he suggested that the changes may be due to the inadequacy of the annual snowfall to maintain a constant flow in cases where the gradient of the glacier is gentle, so that the accumulated load of several years may be required to overcome the rigidity of the ice; but when the limit is overpassed, a phase of active movement is started, and may go on vigorously until the extra load is wholly discharged and the stage of quiescence is again reached.

¹ See "Guide de l'excursion," etc. (*op. cit.*), pp. 13-20, with large-scale ($\frac{1}{500000}$) ground-plans of Von Post, Nordenskiöld, Sefström, Wahlenberg, and Goës Glaciers.

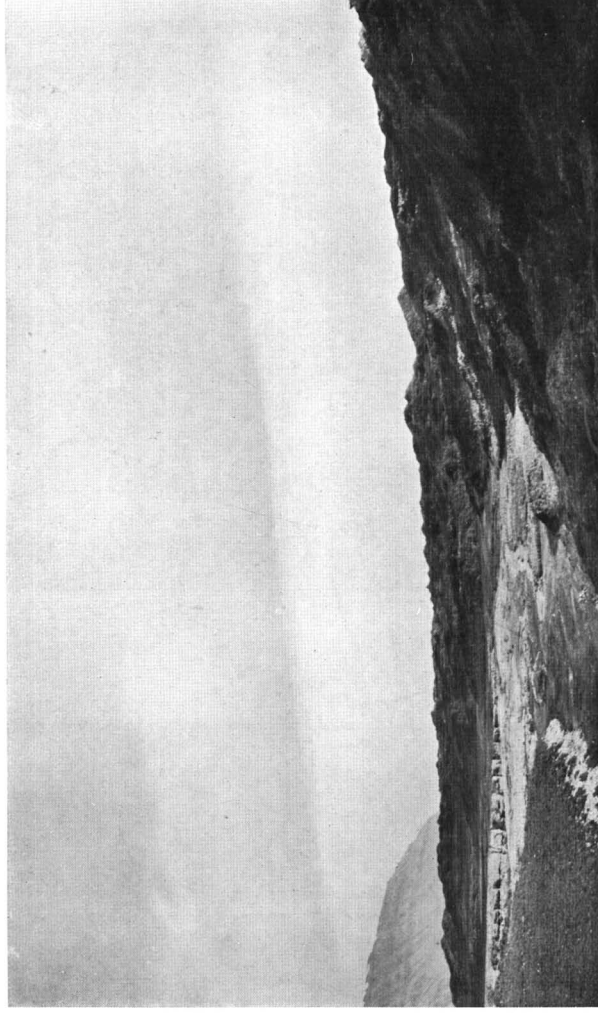
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The Sefström glacier affords the best-known instance of this rapid fluctuation.¹ When first examined by Prof. De Geer in 1882, it ended well within its own inlet, a westerly branch of Ekman Bay, with its sea-front about 2 miles distant from the waters of the main fiord. At this time it was flanked by a broad outwash plain of gravel and sand, which formed the side of the inlet up to the foot of the mountains, only the central portion of the glacier ending in the sea (see Fig. 2).

When re-examined fourteen years later, in 1896, it had undergone an astonishing change. The glacier had filled the bottom of its valley right up to the hills, burying the outwash plain, obliterating the inlet, and bulging out in a broad expanded lobe into Ekman Bay so far that its end had reached the western side of Cora Island, a small low islet lying barely a mile distant from the opposite or eastern side of the bay. The distance covered by this advance was rather more than 4 miles. That its spurt was by this time over, and that recession had already set in, was seen from the condition of another islet, Chert Island, near its southern margin, which showed evidence of having been completely overwhelmed, but was now partly laid bare.

The recession afterwards continued; so that when Prof. De Geer renewed his investigation of the glacier in 1908, its main front of ice-cliffs between the two islands had fallen back at least a mile and a half, leaving an open anchorage for the ship at a spot where there was ice up to 300 feet above sea-level in 1896. It had broken back with a very irregular front, owing mainly, no doubt, to variation in the depth of the sea; and the end which had been pushed on to Cora Island, being firmly aground in shallow water, still remained in position, but had been left isolated by the retreat of the main mass, so that there was a narrow sea-passage westward of the island between the glacier and its detached snout, bordered by great cliffs of ice on both sides. These successive developments are shown in a large-scale ($\frac{1}{50000}$) plan of the glacier prepared by Prof. De Geer for the "Guide," of which, by permission, a reduced copy is given in Fig. 2.

¹ Other examples, including the Von Post, Wahlenberg, and Svea Glaciers, are discussed by Prof. De Geer in the "Guide" (*op. cit.*). Nordenskiöld, many years ago, found similar indications of rapid advance among the glaciers of Bell Sound; *Geol. Mag.* dec. II., Vol. III. (1876), p. 18. Lamont in 1860 described an abandoned shelly moraine off the end of a glacier in Stor Fiord, *Quart. Journ. Geol. Soc.*, Vol. XVI., p. 431; and Feilden has recorded a similar moraine occurring in Green Harbour, *Glacialists' Mag.*, Vol. II (1894), p. 1. Garwood and Gregory's account of the Booming Glacier, *Quart. Journ. Geol. Soc.*, Vol. LIV. (1898) p. 207-8 is another illustration of an active Spitsbergen glacier.



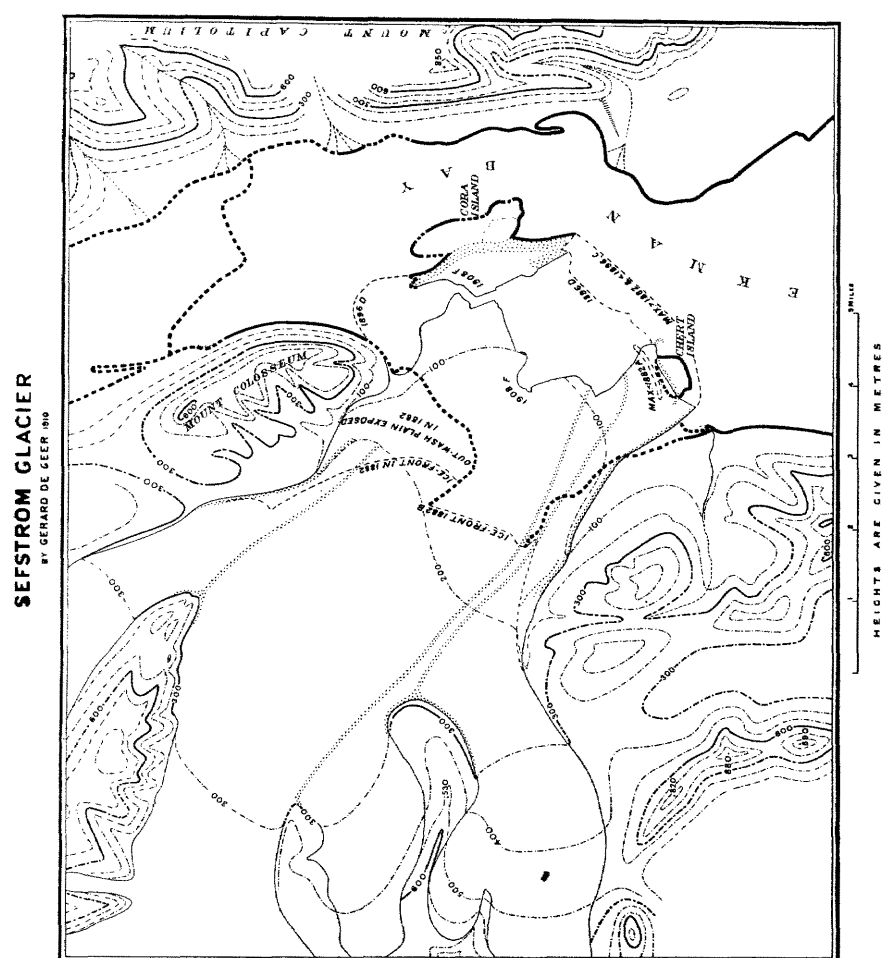
Photographed by Prof. R. S. Tarr.

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Eastern side of the moraine on Cora Island, looking south from near northern end. Moraine on right; bare rocky land on left;
Mt. Capitoleum in background.

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FIG. 2.



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By last August (1910) there had been further recession, and the waterway west of Cora Island had grown broader; but the detached remnant of the glacier, though greatly diminished by melting and undermining, still clung to the island, as shown in Pl. XXVII.

As the result of this glacial invasion, a huge mass of morainic material has been heaped up along the western side of the island, exhibiting remarkable features now to be described.

CORA ISLAND.

In its original condition, the island was a low smooth spit, about 2 miles long by half a mile wide, composed of Carboniferous rocks (chiefly limestone) partly covered with raised beach. There is no evidence that, until the recent invasion, it had ever been covered by ice since its emergence from the sea after the period of the raised beaches. All the charts dating before 1890 show it as surrounded by water; therefore its state in 1896—the year of Prof. De Geer's observations—excited the surprise and interest of another explorer, Mr. A. Trevor-Battye, who had accompanied the expedition of Sir W. M. Conway to Spitsbergen and made an independent journey up Ekman Bay. His account of the island in that year is as follows¹:—

“Upon our Admiralty chart a large island is marked to the north of Ekman Bay, but for this I looked in vain, for reasons which shall presently appear. . . .

“ . . . Early in this exploration I was able to solve the mystery of the undiscoverable island. The Splendid [= *Sefström*] Glacier is advancing at a rapid rate. It now presents three fronts to the sea, a south-western, a south-eastern, and an eastern front. From these two latter faces the glacier rises in a jagged area of seracs. Between the south-western and the south-eastern faces an apex juts boldly out into the sea, and at the time of our visit [*July*, 1896] two immense pinnacles reared themselves from the water, all but separated to their bases from the main mass. This double face of seracs, pushed from behind and undermined by the waves, is constantly falling, so that approach in a boat would be a dangerous experiment. The whole of the sea west of the

¹ “The First Crossing of Spitsbergen,” by Sir W. M. Conway (*Dent & Co., London*), 1897, pp. 243, 249-50.



Photographed by Oscar Halldin, Stockholm.

North end of the moraine on Cora Island.

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large island [*Cora Island*], shown by the survey to have existed there not twenty years ago, is now filled by the advancing glacier. More than half of the island is also overspread. *Without moraine, without dirt or discoloration, the glacier is pouring over it, and great seracs lie there, separated only, or barely separated, from the flowers and the grasses by the clear stream their drip has formed.* [Not italics in original.] A phenomenon more striking than the contrast of the green island with the icy boulders strewn along it, and the grim whiteness which rises so suddenly behind, would be hard to conceive."

From this account it appears that the great moraine now visible was all actually hidden beneath the glacier in 1896. This moraine has doubled the size of the island, and stretches from north-west to south-east in a massive bow nearly three miles long and half a mile wide at its broadest. The convexity of this bow impinges upon the bare island (see Pl. XXVIII.) ; its concavity is still partly filled with the detached remnant of the glacier ; and its two ends run out into the sea, north and south, as tapering spits (see Pl. XXIX., which shows the northern spit).

Our ship steamed up the sound between the present main front of the glacier and the new part of Cora Island on August 7th ; and we landed by small boats, first at the northern, and afterwards at the southern extremity of the moraine, spending several hours ashore upon it—long enough to grasp its principal features, though not long enough to study all its details.

The moraine is composed almost entirely of red clay, intermingled rather sparsely with boulders and with a multitude of marine shells. This material is heaped up into a series of rude confused ridges running in general parallelism with the outer margin of the moraine, but sharply broken by many cauldron-shaped hollows and in a few places by small transverse valleys. The cauldrons range from a few yards to 200 or 300 yards in diameter ; their sides, sometimes 30 or 40 feet high, are steep and crumbling ; and their floors were covered, when we saw them, with muddy water or with sloughs of soft red mud (Pl. XXX.). Their subsidence and the crumbling of their walls were evidently in many cases still in progress, and the presence of oozing muddy pools in them confirmed the supposition that they were due to the melting of patches of ice concealed under the moraine. At

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its highest part, I estimated that the moraine rose at least 70 or 80 feet above sea-level; but it is possible that this height may include some buried ice, and may be reduced when the ice is all melted. On the other hand, in estimating the thickness of the morainic accumulation, allowance must be made for the original depth of the sea in the part now added to island; and it seemed likely that, where thickest, the transported material might be 60 to 100 feet from bottom to top.

From the southern end of the moraine I followed the course of the ridges northward till opposite the place where the mass of unmelted ice still hung to the western side of the island, and I tried then to reach this ice. But the impassable cauldrons increased in numbers and size around its margin, and I failed to find a way across the maze in the time at my disposal. From a distance of 300 or 400 yards, however, I could see (with the aid of field-glasses) that the morainic clay was curiously entangled with the ice, apparently filling crevasses or dike-like gaps in it, which were prolonged in crumbling ridges where the supporting walls had melted or had been withdrawn. Some of our company, including Dr. A. Strahan and Prof. R. S. Tarr, were more fortunate in finding a safe way along the western shore right up to the ice-cliffs, and they saw that wedges of ice were present in places beneath masses of the morainic clay. I am indebted to them for permission to reproduce some photographs showing this condition (Pls. XXXI. to XXXIV.), and to Dr. Strahan for the following description of the phenomena :—

“The cauldrons referred to by Mr. Lamplugh became larger and more abundant as the ice was approached, and the intervening ridges, along which alone a passage through the maze could be effected, became more dilapidated. On reaching the margin it became clear that the morainic material lay, and thinned off gradually, upon a rising slope of clean ice. The margin is illustrated by Plate XXXI. from a photograph by Prof. R. S. Tarr; the ice itself was coarsely granular and presented a gently undulating surface traversed by irregular crevasses. Each crevasse had been filled up with boulder-clay, and the melting of the surface had left these ‘casts of crevasses’ projecting like ruined walls, or still more like igneous dikes. Plate XXXII. was taken from a point farther up on the ice-



Photographed by Oscar Halldin Stockholm.

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Part of the moraine on Cora Island : ridges of red shelly boulder-clay and muddy hollows.

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slope than Plate XXXI. and shows the wet surface of the ice crossed in all directions by 'casts of crevasses.' The subject of Plate XXXI. is included in the left-hand distance, but is not easily distinguishable. The ice-cliff of the Sefström Glacier and the arm of the sea by which it is separated from Cora Island are shown. These two photographs face south-westward.

"A second photograph (Plate XXXIII.) was taken from the same spot as Plate XXXII., but looking eastward. It shows in the foreground the coarsely granular character of the ice and a good example of a 'cast of a crevasse.' A slight depression in the ice farther away holds a pool of water, and beyond this again the moraine which rests on the central part of Cora Island is visible. The mountains in the distance form part of the Mt. Capitoleum range.

"Plate XXXIV. shows the ice cliff at the point where the ice passes under the moraine. The ice is about 50 feet thick, and at its foot, in a deep shadow due to undercutting by the sea, it was possible to see that it rested upon boulder-clay, though the spot was inaccessible. The ice was clean from top to bottom, but that it was underlain by boulder-clay at this spot, and overlain by it close by (Plate XXXI.) was clear."

A. S.

These observations show that the boulder-clay was not pushed forward simply as a separate entity in front of the glacier, but was to some extent actually picked up and entangled with the ice so that it became part and parcel of the advancing glacier. Further, since Mr. Trevor-Battye in his description particularly notes the absence of morainic matter in the ice that he saw on the island, it appears that the transport of the clay was effected by unseen lower layers of ice. When its bottom impinged upon the rising bank which forms the basis of the island, the glacier evidently ploughed up the soft sea-floor and incorporated large masses of the material in its under part. This load was carried forward to the limits reached by the glacier; and if the forward movement had continued, there is no reason to doubt that a large portion would have been transported as far as the lower layers advanced. The case is a clear illustration of the method by which marine detritus may be carried over the land during progressive glaciation.

Further description of the Moraine.

The red clay of the moraine has been derived mainly from the disintegration of the red Devonian rocks—marls and sandstones—which underlie the bottom of the fiord and rise above sea-level to the north and east of Cora Island. The waters of Ekman Bay are deeply tinged, especially in the neighbourhood of the glaciers, with red mud brought in by streams; and this material must be deposited in quantity on the sea-bottom. Some of the clay of the moraine may have been derived directly from the solid rocks by glacial abrasion, but certainly the greater part has come from the muddy deposits of the fiord. So far as I saw, however, there was no sign of lamination or stratification in the mass; if any such structure existed before transport, it had been obliterated.

I have it in my notes that the colour of the clay seemed to me “a little redder than the Purple Clay of Yorkshire but not quite so red as the Hesse”; and that the proportion of boulders was “about the same as in Yorkshire clays, or a little more.” The clay was rather loamy and crumbling where dry—not so hard as our Yorkshire boulder clays—but was tough and sticky where wet. It was laced here and there with streaks of grey-green colour, containing crushed shale, very like the streaks one sees in the ‘red band’ of our Holderness drift-sections; and this seemed to imply the derivation of such portions from fresh unweathered rock.

All the boulders that I saw were from the local formations, chiefly grey and purple sandstones, limestones, chert, conglomerate, etc. Some were striated; others, about equal in number, had no striæ; and a few were angular. Many were thickly encrusted with a sea-growth of *Lithothamnion*, showing that they had lain on the bottom of the fiord; and I noticed limestone boulders with molluscan borings, like those we find occasionally in the Holderness boulder-clays. The boulders were distributed somewhat patchily, as in most boulder clays, being sometimes clustered and sometimes widely spaced. There were a few gravelly streaks and pockets in the clay, but I saw no regular stratified deposits of any kind, the scantiness of fluvio-glacial detritus striking me as remarkable and unexpected.

Save for a stray and exceptional tuft of grass the whole area of the moraine was absolutely bare; its material was likewise exposed in section in the steep walls of the cauldrons, and in the



Photographed by Prof. R. S. Tarr.

Reproduced by his permission.
Glacier-ice on west side of Cora Island, with interspersed masses of red boulder-clay.

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low sea-cliffs at both ends of the island where it had almost exactly the appearance of a boulder-clay of the Yorkshire or Lancashire coast. The shells were everywhere abundant and conspicuous on the surface; they were present also in all the sections that I examined, but I thought that they were more plentiful at the top than in the deeper clay—perhaps, however, only because they were less conspicuous when seen edgewise and unwashed.

The fortunate interposition of this bit of ground rising from the sea in the path of the advancing glacier has indeed presented an opportunity which is perhaps unique under existing conditions. The glacier came to land again on a low shelving coast after traversing the sea-bottom; and I know of no other present example of this phenomenon, though we have reason to believe that it was a common condition during the Pleistocene glaciation. To me, one of the most impressive features of the moraine was its abrupt termination upon the bare ground of the island (see Pl. XXVIII. and Figs. 3 and 4).

The original low shelf of gently inclined rock and old beach-shingle forming Cora Island probably nowhere rises to more than 30 or 40 feet above present sea-level, and most of it is considerably lower than this. It supports the usual scanty tundra-growth of the Spitsbergen lowlands, this growth being continuous close up to the red clay of the moraine, and there stopping abruptly. From Mr. Trevor-Battye's description and from the height of the unmelted remnant of ice, it is clear that the glacier shot forward over the island-shelf with a dominating front rising high above the land-level. Part of its height was due to the intercalated foundation of moraine that it had dragged along; and this foundation must have extended close up to the front of the glacier, though apparently it was hidden by higher layers of clean ice at the time of Mr. Trevor-Battye's visit.

The great moraine now marks out very closely the limits reached by the ice. As shown in Pl. XXVIII., the ridges of red clay rise up boldly above all the smooth low tundra that lay beyond reach of the invader; and though the transported mass sinks lower towards its outer margin, it ended wherever I saw it in a very definite bank several feet in height, from which one could step in a few strides on to the undisturbed tundra.

FIG. 3.

Diagrammatic section across Cora Island to the front of the Sefström Glacier (1910).

Scale (approximate) :—Horizontal, 3 inches = 1 mile : Vertical, $\times 3$.

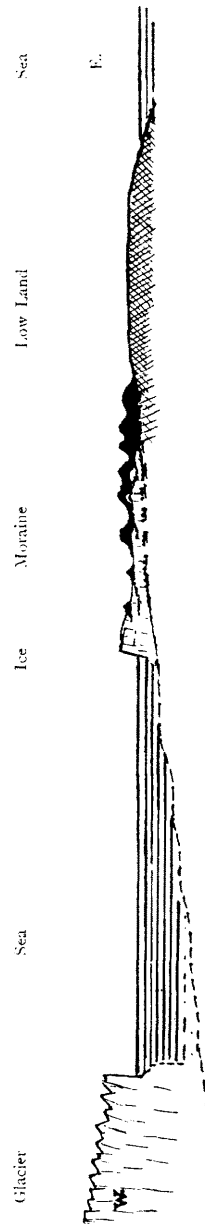


FIG. 4.

Diagrammatic section across the central part of the moraine on Cora Island.

Scale (approximate) :—Horizontal, 9 inches = 1 mile : Vertical, $\times 2$.





Photographed by Dr. A. Strahan.

Surface of the glacier-remnant on Cora Island with incorporated masses of morainic clay : the retreating front of the Seisström Glacier in the background.

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The slope of the original surface being toward the moraine, there is now a slight depression, with the moraine on the western side, and the unglaciated land on the east. The drainage from the melting ice has followed this depression northward and southward to the sea, along the periphery of the moraine, slightly eroding its margin and still further accentuating the abruptness of its termination ; but the gradient is too gentle and the elevation too low to leave much play for erosion. In traversing, here and there, the beds of these now-dry watercourses, I was surprised by the scantiness of gravel or other water-borne sediments ; the extinct streams have doubtless carried their fine mud in suspension to the sea, and they seem to have had very little heavier material to transport.

This absence of a fringe of fluvio-glacial detritus was unexpected, as one had been inclined to regard such a fringe as an essential concomitant of an ice-border on low ground. Its absence in this case was, however, readily explained by our leader, who pointed out that very little of the drainage of the glacier could ever cross the deep trough of the fiord, and that as soon as the ice began to recede from the island, nearly all its surface-drainage would fall backward into the trough. Prof. De Geer showed us, nevertheless, a short transverse valley crossing the moraine near its northern end, which he knew to have been cut by water flowing from the glacier, as he had seen a stream issuing from the ice at this point in 1896.

The relations of the moraine to the original island are illustrated diagrammatically in Figs. 3 and 4, which are based on rough sketches that I made on the spot.

The Shells of the Moraine.

Of course, the point of surpassing interest on Cora Island to an East Yorkshire glacialist was the presence of shells in the moraine. Personally, ever since I began the study of our drifts over 30 years ago, I have been convinced that the transport of shells was effected on a large scale by the ice-sheets of the Glacial period in passing over the floors of our seas ; from time to time I had read of modern instances of the process in Norway,¹ Greenland² and Spitsbergen³ ; and here, at last, I saw for myself a

¹ A. Geikie, "Geological Sketches at Home and Abroad" (London, 1882) pp. 145-6.

² R. D. Salisbury, "Glacial Geology." *Rep. Geol. Surv. of New Jersey*, Vol. V. (1902), p. 81.

³ E. J. Garwood and J. W. Gregory ; also A. E. Nordenskiöld, J. Lamont and H. W. Feilchen ; all in works cited in footnote on p. 222 ; and H. Backlund (Négri Glacier on east coast) in "Missions Scientifiques pour la Mesure d'un Arc, etc.," *Mission Russe*, tome II., Sec. IX., (1908), p. 10.

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complete demonstration of it. The advancing glacier had acted like a great dredge ; in crossing the trough of the fiord, it had dragged the material of the sea-bottom up the slope and spread it out for investigation upon the land.¹ Moreover, it had done its dredging work so effectively that the majority of the shells had not been injured by their removal. Their state of preservation was indeed astonishing, as was also their profusion. Evidently the neighbourhood sea at a moderate depth is full of life, though the winter frosts and the formation of ice-foot along the shore render the conditions intolerable to molluscan life between tide-marks, so that usually there were few shells to be seen on the foreshore except such as were derived from elevated marine beds of the raised-beach period. But on Cora Island the beach was crowded with shells, undoubtedly derived from the moraine.

Over every part of the moraine that I traversed, the shells were present, clustered thickly in some places and thinly scattered in others ; and fragments of *Lithothamnion* were even more plentiful than the shells, sometimes occurring in twisted streaks that resembled in appearance the streaks of chalk-detritus so common in the Holderness boulder-clays. Bivalves greatly predominated, mainly species of *Astarte*, *Mya*, *Pecten* and *Tellina* ; but there was likewise a sprinkling of univalves, chiefly species of *Natica* and *Buccinum*. In many cases the epidermis was still fresh on the forms like *Astarte* which have this covering ; and a great many of the bivalves occurred with the shells closely united as in life, and in some cases with the shrivelled ligament still in position. The interior of the paired bivalves was usually filled with red clay like the matrix in which they were embedded ; in two or three instances, however, I found that the infilling material was more sandy and paler than the matrix, though the difference was not so marked as that which has been occasionally observed in the interior of shells from the Yorkshire boulder-clays. Isolated valves were common, and some of the shells were broken ; but perfect shells and paired valves predominated.

I had no time for systematic collecting, and merely filled my pocket with shells that came in my way, therefore obtaining only the commoner forms. The richness of the fauna is shown by the

¹ [P.S. Sept. 1911.] Prof. G. A. J. Cole, in the paper cited on p 216, suggests that the material may have been transported from raised beaches on the western shore of Ekman Bay ; but the fresh condition of the shells, the medial position of the moraine in respect to the front of the glacier, and indeed all the circumstances, appeared to me to indicate that it was derived from the bottom of the fiord and not from the shores.



photographed by Dr. A. Strahan.

Surface of the glacier-remnant on Cora Island, with a dike-like ridge of morainic clay in the foreground ; and the main mass of the moraine in the middle distance.

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list given on p. 235, for which I am indebted to Prof. De Geer. My own gleaning was made up of the following species (I use the older names by which the shells are best known to British glacialists):—*Astarte elliptica*, *Astarte borealis*, *Mya truncata*, *Pecten islandicus*, *Tellina calcarea*—all of which were very plentiful; and I had, besides a large and perfect specimen of *Cardium groenlandicum* (a rather fragile shell), some broken valves of *Mytilus edulis*, a *Natica*, and a *Buccinum*.

This, it will be noted, is precisely such a list as we should get most easily in collecting shells from the East Yorkshire boulder-clays, except that *Tellina balthica* would take the place of *Tellina calcarea* (which is very rare in our drifts) and we should be sure of including also *Cyprina islandica* (which has likewise been found on Cora Island, but not by me).

There is one strong difference, however, in the profusion of the coral-like calcareous *Lithothamnion* which I do not remember ever to have seen in our shelly drifts, while on Cora Island it was everywhere; and some of the dead shells of the big pectens had been so thickly coated with encrusting growths, that they had the shape of small birds' nests.

The seaward front of the moraine is now being steadily wasted by the waves, and the clay is carried away in suspension while the shells and *Lithothamnion*-débris are swept alongshore to the south end of the island where they are cast upon a low curving spit, practically unmixed with any other material. This glaring white beach, shown in Pl. XXXV., is at present the best collecting-ground in Ice Fiord for shells. First the glacier did the dredging; then the sea did the washing and sifting; and now, as may be seen in the picture, the conchologist can do the collecting at his ease!

I have previously mentioned that there are to be found in the raised beaches around Ice Fiord certain species of shells which no longer live in its waters, and that these are regarded as evidence of a somewhat warmer climate in comparatively recent times. Five such species (classed as "Post-glacial" in the appended list, p. 235) are included in Prof. De Geer's collection from Cora Island. Their occurrence furnishes another point of analogy between the Sefström moraine and the British shelly drifts wherein there is often an admixture of species that probably lived under different conditions of depth and temperature.

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It is evident that many of the shells now on Cora Island are the relics of molluscs that were actually alive just before the advancing glacier swept them from their habitat in the fiord, along with the clay deposited there. The presence of the species not now extant indicates, however, that the glacier did not merely scrape the surface of the sea-floor, but ploughed down into it ; for the muddy waters of the bay must constantly precipitate much sediment, so that the ancient shells were probably buried at some depth. The abundance of *Mytilus edulis* in the moraine shows that, whatever may have been the thickness of the overlying sediment, the ice-plough went, at any rate, deep enough to reach and transport the layers representing the by-gone period of milder conditions.

It is hardly possible to fix the exact distance that the shells have been carried, as we do not know at what stage of its advance the glacier began its dredging. Presumably the effect was greatest when the ice impinged on the rising slope of the sea-bottom near the island, in which case the distance would not be over a mile ; but if the operation began earlier, the shells may have been carried for three or four miles. The vertical uplift from the deepest part of the fiord to the highest part of the moraine may have been about 250 feet ; in most cases it has probably been somewhere between 50 and 100 feet. Even with so short a journey, the marine material showed hardly any trace of its original order, except in some patches, seen by Dr. Strahan, in the portion still entangled with the ice. If the glacier had continued to move forward, the material must have been carried farther ; in fact there is every probability that some part of it would have been carried along to the farthest limits attained by the ice, and would there have been cast down pell-mell, as soon as the retreat set in. During a longer journey, however, the shells could hardly have retained their perfect condition ; they would have 'gone farther and fared worse,' becoming gradually reduced to the fragmentary and travel-worn state of the specimens with which we are so familiar in our British shelly drifts ; but in the patches of 'Bridlington Crag' of the Basement Boulder Clay of Bridlington, South Sea Landing, and Dimlington, the shells are in the same condition as those of the Sefström moraine.



Photographed by Dr. A. Strahan.

The glacier-remnant on Cora Island, surmounting, and mixed with, the shelly moraine.

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Prof. De Geer, who has got together an extensive collection of the Cora Island shells, has kindly sent me for publication the following list, not hitherto published, of the species already identified.

List of the Shells, etc., from Cora Island.

“ Post-glacial and recent marine shells pushed up between 1882-96 by the advancing Sefström glacier in the great terminal moraine on Cora Island in Ekman Bay of the Ice Fiord, Spitsbergen, from depths between 0-50 meters ” :—(*Signed*) “ Gerard De Geer, Stockholm, 31st May, 1911.”

“ Post-glacial species.

Anomia ephippium *Lin.*

Mytilus edulis *Lin.*

Cyprina islandica *Lin.*

Litorina rudis *Maton*

Onoba aculeus *Gould*

Recent species.

Pecten islandicus *Müll.*

Crenella lævigata *Gray*

Crenella decussata *Mont.*

Leda pernula *Müll.*

Yoldia (*Portlandia*) *arctica* *Gray*

Cardium ciliatum *Fabr.*

Cardium groenlandicum *Chemn.*

Astarte borealis *Chemn.*

Astarte compressa *Mont.*

Astarte elliptica *Brown*

Axinus gouldii *Phil.*

Tellina calcaria *Chemn.*

Mya truncata *Lin.*

Saxicava rugosa *Lin.* var. *pholadis*.

Chiton marmoreus *Fabr.*

Tectura rubella *Fabr.*

Lepeta cæca *Müll.*

Puncturella noachina *Lin.*

Moelleria costulata *Möll.*

Margarita helicina *Fabr.*

Margarita groenlandica *Chemn.*

Natica affinis *Gmel.*

Lacuna crassior *Mont. ?*

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Cingula castanea Möll.
Bela elegans Möll.
Bela bicarinata Couth.
Trophon clathratus Lin.
Buccinum glaciale Lin.
Buccinum tenue Gray
Buccinum groenlandicum Chemn.
Echinus droebakensis Müll.
Balanus porcatus da Costa
Serpula sp.
Spirorbis sp.
Foraminifera (especially a great *Biloculina*).
Ostracoda
Bryozoa
Lithothamnion (predominant)."

NORDENSKIÖLD GLACIER.

Reference has already been made to other instances of shelly moraines which have been observed in association with Spitsbergen glaciers,¹ though none appears to have been so remarkable as the Sefström example. The only other case which we saw during our recent journey was that of the Nordenskiöld Glacier.

This great glacier comes down to the sea in the eastern arm of Klaas Billen Bay (see Fig. 1), ending off with an ice-front of three miles in water nearly 500 feet deep. It has shown only minor changes since its measurement in 1882; and the extension of a series of raised beaches close up to its southern margin proves that it cannot have reached much beyond its present bounds at any time since the beaches were formed. It has slightly invaded these beaches and incorporated some of their shelly material in its southern lateral moraine. This moraine is composed mainly of very stony grey clay derived from the Carboniferous rocks. We examined it in the gully cut by a strong stream flowing from the flank of the glacier, and found a few shells, mostly in dispersed fragments and in a state of preservation very different from that of the Cora Island shells. Here, of course, there was no chance of seeing what has happened under the seaward front of the glacier; it is merely the already weathered material of the raised beach that has supplied the marine detritus to the lateral moraine.

¹ See footnote references on p. 231.



Photographed by Oscar Halldin, Stockholm.

Reproduced by permission of Prof. G. De Geer.
Spit at south end of Cora Island, composed of lithothamnion-débris and shells derived from the moraine. Mt. Capitoileum in the background.

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Nevertheless the instance was instructive, in showing how readily shells and other beach-material are incorporated with glacial deposits when they come within reach of moving land-ice. It was difficult, in some of the sections, to tell where the raised beaches ended and the moraine began.

VON POST GLACIER.

Another tide-water glacier that we visited in Ice Fiord was the splendid Von Post Glacier at the head of Temple Bay (Pl. XXXVI.). The sea-front of this glacier is about $2\frac{1}{2}$ miles wide, and rises to nearly 300 feet above water. A large-scale ($\frac{1}{50000}$) plan published by Prof. De Geer in the "Guide de l'excursion" shows that the glacier has been in slow retreat since 1883. Before then, it had fallen back nearly a mile from an earlier maximum, as indicated by its lateral moraines which extend for about $1\frac{1}{2}$ mile beyond its present front. Its terminal moraine is submerged under the waters of the inlet; but the lateral moraines line both shores of Temple Bay, and their internal composition is clearly revealed in wave-cut cliffs.

As seen in the cliff-sections, 10 to 50 feet high, the lateral moraines have a homogeneous structure. They are composed of rather sandy red clay, sufficiently compact to be traversed by vertical joints and to break down from the cliffs in big slices, after the fashion of our British boulder-clays. On both sides of the bay we landed at the foot of these cliffs which were strongly reminiscent of similar cliffs known to me on the coasts of North-east Yorkshire, the Isle of Man, and other parts of our Islands. We examined some parts of the moraine that had been exposed by the recession of the ice since 1883.

The clayey matrix was studded with numerous boulders of varied size, many of them worn and highly glaciated, and of diverse composition, including many igneous and metamorphic rocks, along with grey and red sandstones, conglomerates, chert, Carboniferous limestones and other sedimentary rocks. The end of the glacier lies in a region of grey Carboniferous strata, with no older formations visible in the neighbourhood; but it is known that more ancient rocks crop out to the northward, among the ice-fields of the interior; and it is evident that the glacier has transported most of the material of its moraines, including the red clay and the igneous and metamorphic boulders, from its concealed bed and from its upper basin. The absence of shells

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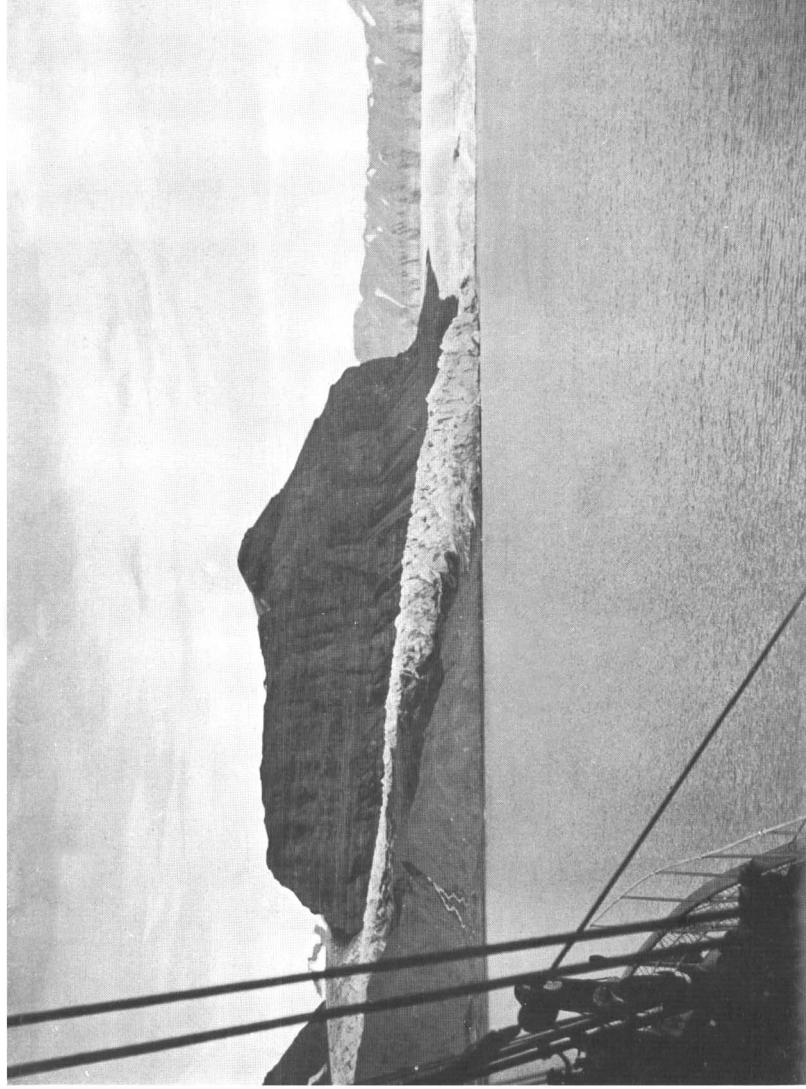
or other marine detritus showed that in this case we had to deal with the land-spoil of the glacier and not with re-distributed marine deposits.

Though the seaward cliffs of the moraine, so far as I saw them, were composed throughout of this red boulder-clay, there must have been places farther from the sea where grey Carboniferous detritus of local origin was mixed in preponderant quantity with the red drift, as the morainic rock-waste on the surface of the ice at the southern flank of the glacier appeared to be mainly constituted of such local material. In traversing some moraine-covered ice on this flank, I noticed that amid the sheets of angular grey Carboniferous rubble there were streaky patches, here and there, of dirty red ice, carrying some well-glaciated boulders of the ancient rocks. It was clear that at these places the deeper moraine was somehow being brought up to the surface of the glacier. Fortunately, the moraine-charged ice near the southern edge of the glacier was notched by a deeply-cut stream-gully, accessible from the shore. The section in the walls of this gully near its mouth exhibited moraine-laden ice bent into sharp upward curves and sigmoidal contortions (see Pl. XXXVII.) ; and in one place a belt of ice sweeping boldly upward was charged with red mud and scratched stones, while above and below the ice was charged with the dull grey local débris. The section, in fact, beautifully illustrated the conditions, described by Garwood and Gregory in other Spitsbergen localities, whereby the lower layers near the end of a glacier are deflected upward along shear planes and brought to the surface.¹

If it came about that this glacier received no further accession, so that it became stagnant and now melted down without movement, it would leave as a residue, in the part we saw, two very different kinds of drift ; the lower, a red clay with far-transported stones ; the upper, a grey rubbly clay with a preponderance of local stones, mostly unglaciated ; and the two would show, in some places, complicated inter-digitation and banding.

In our British drifts it has often been deduced that a difference of composition in successive beds of boulder-clay implies separate periods of glaciation ; but the evidence of the Von Post moraines shows that the deduction is unsafe.

¹ Op. cit. *Quart. Journ. Geol. Soc.*, Vol. LIV. (1898), p. 203 *et seq.*



Photographed by Oscar Halldin, Stockholm.

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North end of Yon Post Glacier, Temple Bay, on right, with former tributary, now separated from it, on left.

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The general arrangement of the *lateral* moraines of the Von Post Glacier resembles in many respects that of the *terminal* moraine of the Sefström glacier; they are heaped up in a similar though narrower plexus of ridges which on the north side of the bay (where I saw them best) rise sharply above lower ground that has lain beyond reach of the glacier in its advance. The waters of the bay are deep, sinking so rapidly on the northern side that there are soundings of 200 feet within about 250 yards of the shore (*fide* Prof. De Geer's map), and it is surprising that so much of the bottom-moraine of the glacier should have been extruded above sea-level on its flanks. Apparently here, as on Cora Island, the ruling factor has been the rising slope upon which the ice impinged, in the one case laterally, in the other case frontally. In both cases the pressure of the glacier upon the slopes seems to have had the effect of squeezing upward and outward the moraine-laden layers from the lower part of the moving mass.

The ridges of boulder-clay forming the northern moraine rise to 40 or 50 feet above the sea and run parallel to the shore, or, in other words, to the former flank of the glacier. This moraine varies in width; I noted one spot where it was not more than 60 or 70 yards across. A longitudinal hollow occupied by a pond of water intervened between it and the steep mountain-side, but was being rapidly filled by detritus from the adjacent screes-slopes and by fluvio-glacial wash brought down from the ends of two small glaciers in tributary valleys.

The corresponding moraine on the southern side of the bay is broader and higher, probably rising to over 100 feet above sea, but I had not sufficient time to gauge its dimensions or to examine its landward edge.

CONSIDERATIONS AFFECTING BRITISH DRIFTS

Most of the facts that I have reviewed in the above pages were, as already acknowledged, previously known to glacialists, particularly to those of Scandinavia; but they deserve to be restated for the purpose of emphasizing their application to some problems of our British drifts. It remains for me to summarise the points that, in my opinion, are most instructive in this connection.

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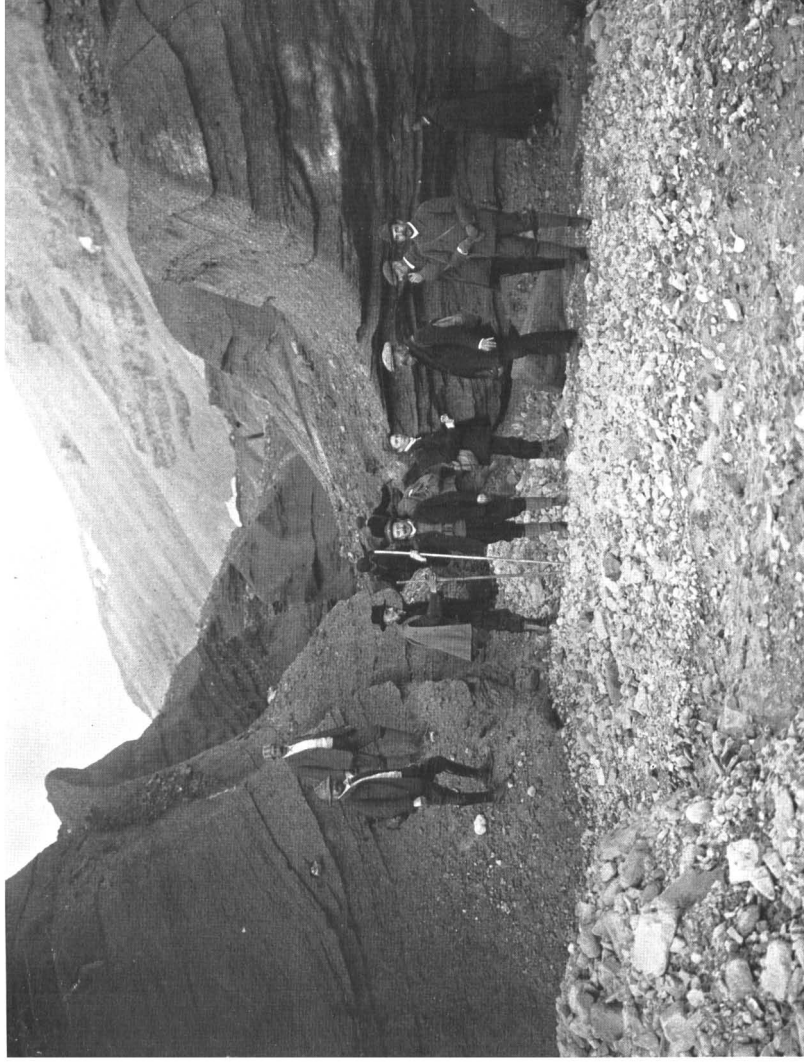
(1) There is proof of a former spread of glaciation over practically the whole of Spitsbergen ; yet, on the extensive tracts of land now bare, there is seldom any conspicuous evidence of this event, its traces on the country above present sea-level having been reduced by later erosion to remnants difficult of recognition. On the whole, there is much more drift in an equivalent area of the British Islands than is now visible in Spitsbergen.

(2) Under arctic conditions, stratified rocks similar to those covering large areas of our own country are disintegrated to a state which would favour the production of boulder-clay in quantity when the areas were invaded by moving ice. Material of this kind is seen to be readily caught up and transported by glaciers, and is discharged in huge masses at or near their ends.

(3) The moraines at and around the ends of some of the Spitsbergen glaciers bear a close resemblance in composition and structure to some of our British boulder-clays, this being particularly striking in a terminal moraine of the Sefström Glacier and in the lateral moraines of the Von Post Glacier. The red clay of these moraines is heaped up in ridges and mounds higher than neighbouring unglaciated low ground and terminates abruptly upon it. The local absence of fluvio-glacial outwash was very noticeable at the Sefström terminal moraine on Cora Island. This recalls the conditions on the eastern slope of the Yorkshire Wolds, where the red boulder-clay ends off irregularly and indefinitely upon the rising ground of bare chalk.

(4) The presence of vast numbers of shells, mostly unbroken, in the terminal moraine of the Sefström Glacier after it had crossed an arm of the sea shows how readily marine material can be hoisted up from the sea-floor and transported by an advancing sheet of land-ice. It illustrates the manner in which our shelly drifts have been spread by the ice-sheets of the Glacial period over the land surrounding our sea-basins. The admixture of certain shells not now living in Spitsbergen waters adds to the analogy.

(5) The sudden advance of the ice on Cora Island seems to have caused no interruption of the previous conditions on the ground not reached by the glacier ; which shows that the influx of land-ice need not greatly interfere with the state of adjacent land. In this latitude the flora and fauna inhabiting the land



Photographed by Oscar Halldin, Stockholm.

South end of Von Post Glacier ; the cliff and gully are cut in contorted ice-laden with morainic material.

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are of the scanty arctic type ; but under similar circumstances at lower latitudes, as for example, in Alaska and Patagonia, a dense covering of vegetation is found close up to the ice-margins. It is likely that throughout the Glacial period any part of our Islands that was permanently, or even temporarily, bare of ice would be tenanted by plants and animals in a similar manner. There is much probability that the Pleistocene fauna of Britain was adapted to such conditions, and was in part contemporaneous with the waxing and waning ice-sheets.

(6) The local piling up of a mass of boulder-clay, to a thickness of 100 feet or more, by the Sefström glacier during its brief invasion of Cora Island, an invasion lasting certainly less than 10 years and probably not more than 4 or 5 years, shows how rapidly the glacial deposits may sometimes be accumulated. The conditions in this case were comparable to those of our Eastern lowlands. It is evident from this that no safe conclusion as to the duration of glaciation can be deduced from the thickness of the boulder-clay at any particular spot. We know from other evidence that the glaciation of our Islands was a slow and very lengthy process ; but it may nevertheless have happened that some of our thickest drifts in the marginal areas were accumulated during a particular phase of very short duration. The greatest amount of drift is deposited near the limits reached by the ice ; consequently, the thickness of the glacial deposits must often be in inverse ratio to the time-factor of glaciation.

NOTE.—For the photographs reproduced in illustration of this paper, I am indebted to Prof. G. De Geer, Dr. A. Strahan, F.R.S., and Prof. R. S. Tarr, who have kindly consented to this use of them. I have further to thank Prof. De Geer for permission to reproduce his map of the Sefström Glacier, and for the list of shells and much other information and advice ; and Dr. Strahan for writing the description of the conditions around the glacier-remnant on Cora Island.